

Mission and vision of the Department

Vision of Mechanical Department

To establish the state of the art learning center in Mechanical Engineering which will impart global competence, enterprising skills, professional attitude and human values in the student.

Mission of Mechanical Department

1. To impart quality technical education to the students.
2. To develop comprehensive competence in the students through various modes of learning.
3. To enable students for higher studies and competitive examinations.
4. To facilitate students and industry professionals for continuous improvement and innovation.

Program Educational Objectives:

[1] Use core competence acquired in various areas of Mechanical Engineering to solve techno-managerial issues for creating innovative products that lead to better livelihoods & economy of resources.

[2] To establish themselves as effective collaborators and innovators to address technical, managerial and social challenges.

[3] To equip students for their professional development through lifelong learning and career advancement along with organizational growth.

[4] Serve as a driving force for proactive change in industry, society and nation.

PROGRAM SPECIFIC OUTCOMES

Student should have

- 1) An ability to work professionally in mechanical systems including design, analysis, production, measurement and quality control.
- 2) An ability to work on diverse disciplinary tasks including manufacturing, materials, thermal, automobile, robotics, mechatronics, engineering software tools, automation and computational fluid dynamics.

Jawaharlal Nehru Engineering College

Laboratory Manual

Engineering Metallurgy

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Experiment No. 1

Title: Study of the different crystal systems.

1.1 Theory

The electronic structure of the atom determines the atomic bonding, which in turn imparts general properties to metals, ceramics, and polymers.

The structure of material may be divided into four levels - atomic structure, atomic arrangement, microstructure and macrostructure.

Atomic structure influences how the atoms are bonded together, which in turn helps us to categorize material as metals, ceramics, and polymers and permits us to draw some conclusions about the mechanical properties and physical behavior of these classes of materials.

Atomic arrangement plays an important role in determining the microstructure and behavior of a solid material. Properties of an individual atom are determined by its atomic structure where its valence electrons play an important role in producing most of its chemical, electrical, optical properties. These atoms combined together to form crystals. The arrangement of atom in the interior of a crystal is called crystal structure.

This structure is determined by grouping of the atoms, bonding between them, type of space lattice, formal parameters of the unit cell and the number and the positions of atoms per unit cell.

1.2 Grouping of atoms

Metals are aggregate atoms. Metallic properties depend not only on the nature of atoms but also on the manner in which numbers have been assembled.

Materials can be categorized into three categories:

- (a) Molecular Structure
- (b) Crystal Structure
- (c) Amorphous nature

1.3 Bonding in solids

All the atoms of a crystal have definite types of attractive forces among themselves, which keep the atoms bonded together.

The attractive forces could be of following types

- (a) Metallic bond: Good electric conductor
Have good conductivity
- (b) Covalent bond: Poor ductility
Poor electrical conductivity
- (c) Ionic bond: Poor electrical conductivity
High hardness
High melting point
- (d) Van der Waals bond: Soft
Low melting point
Poor electrical conductivity

1.4 Space lattice and unit cell

A crystalline substance, which is one that is made of crystals or part of crystals. In a case crystal, the atoms are arranged in a periodic and regular pattern in space. The arrangement of atoms in a crystal can be described with respect to a three dimensional net of straight lines called space lattice as shown on fig.

The intersections of a line are points of a space lattice. The atoms in a crystal may occupy these points or they may be points about which several atoms are clustered.

The unit cell is a sub division of the lattice that still remains the characteristics of the lattice as shown in fig. A unit cell is a building block of the crystal. The crystal consists unit cells stacked tightly together, each identical size shape and orientations with all other.

Shape and size of unit cell is given by six lattice parameters $a, b, c, \alpha, \beta, \gamma$ and as shown in fig.

Depending upon the relation between these parameters, the unit cell can be divided in to seven groups known as crystal systems.

The simplest possible relation between the lattice parameters exists when all three ones are equal and angle between them is 90 degree. This group is known as cubic system. Other crystal systems and the relation - ship between the lattice parameter are given in the table. The seven different types of crystal systems can be further sub divided into 14 Bravis lattices as shown in figure.

There are three different basic arrangements for atom within a unit cell.

- Simple with lattice points only at the cell corners (SC)
- Face centered arrangement with lattice points at the center of the volume of the unit cell. (FCC)
- Body central arrangement with lattice points at the center of the volume of the unit cell.(BCC)

1.5 Definitions

Lattice parameter - the lattice parameter, which describes the size and shape of the unit cell, include dimensions of the sides of the unit cell and the angle between the sides.

The length measured at room temperature is the lattice parameter a_0 unit in angstrom.

$$1 \text{ angstrom (A)} = 10^{-8} \text{ cm} = 10^{-10} \text{ m.}$$

Structure	a_0	Co- ordinate number	P. F.	Type of metals
SC	$a_0=2r$	6	.52	None
BCC	$a_0 = 4r/\sqrt{3}$	8	.68	Fe, Ti, W, Mo, Mb, Ta, K, Na, V, Cr, Zr
FCC	$a_0 = 4r/\sqrt{2}$	12	.74	Fe, Cu, Al, Ag, Pb, Ni, Pt
CPH (HCP)	$a_0=2r$	12	.74	Ti, Mg, Zn, Be, Co, Cd

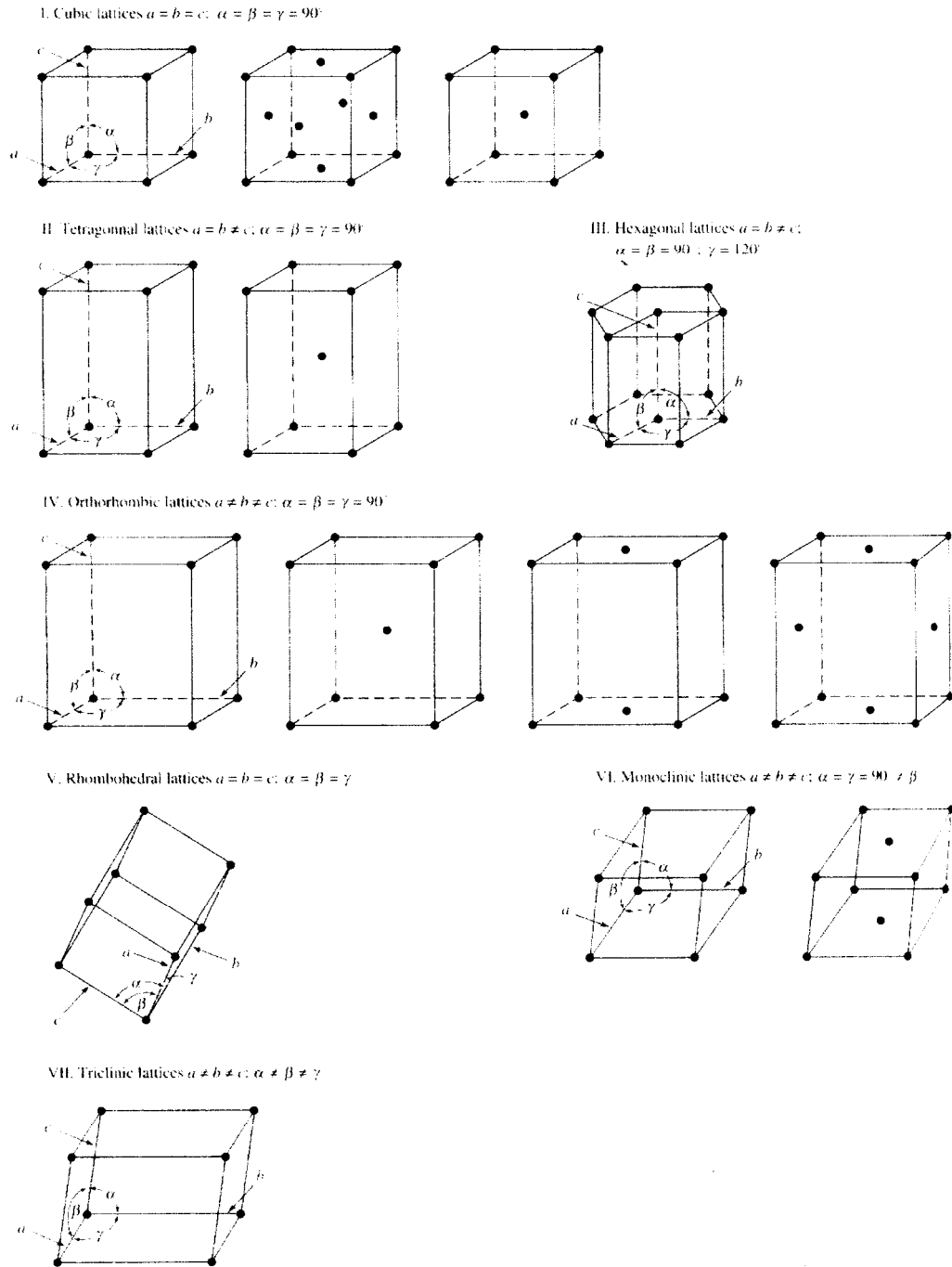


Figure 1.1 the 14 Bravais lattice grouped into 7 lattice types.

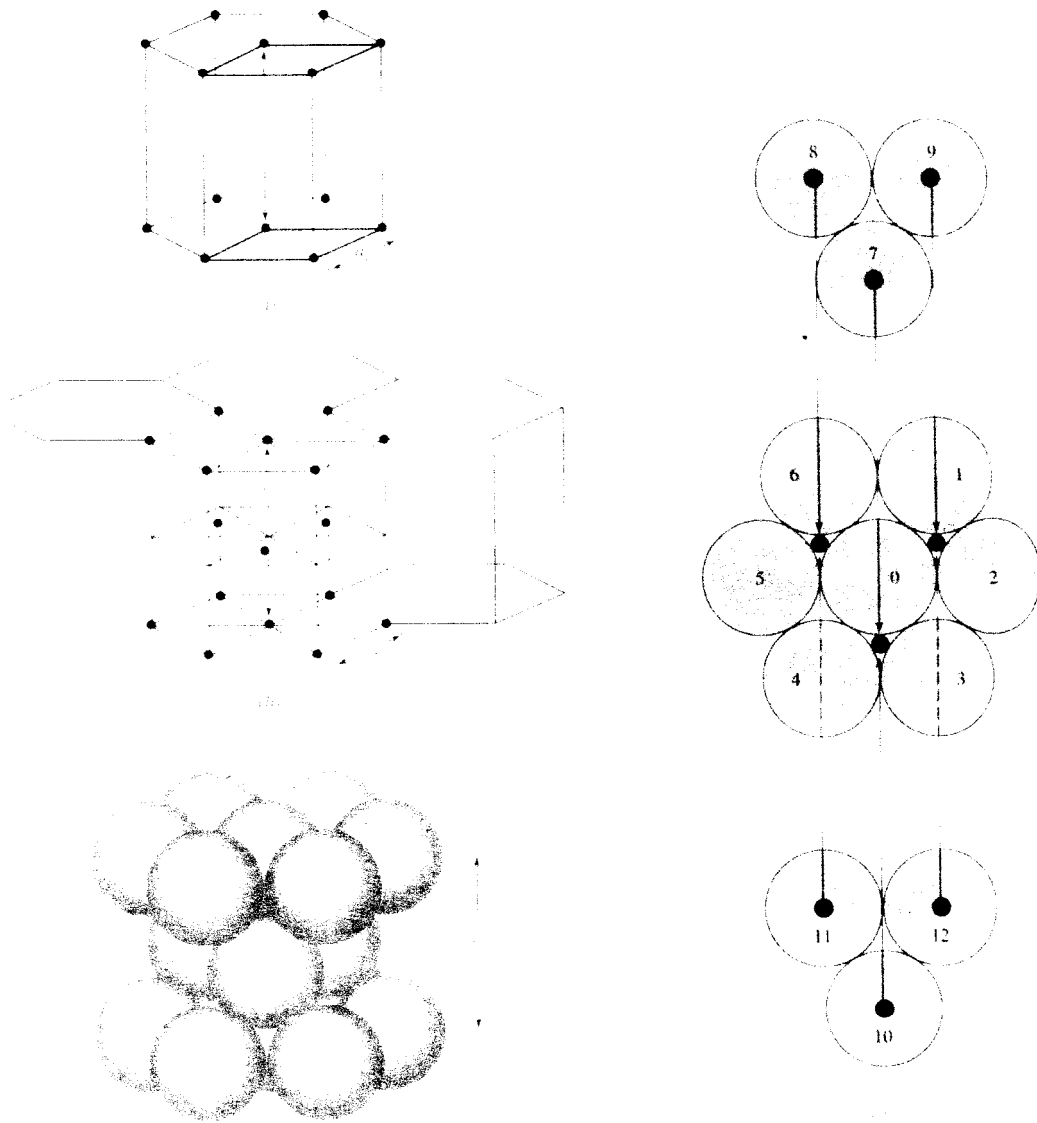
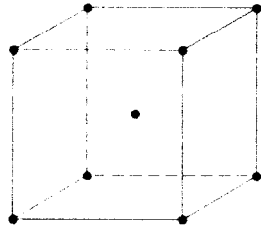


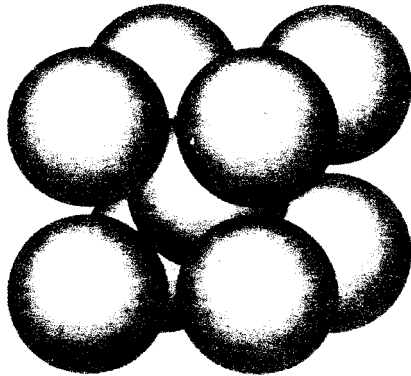
Figure .4 The structure of simple and hexagonal closed pack



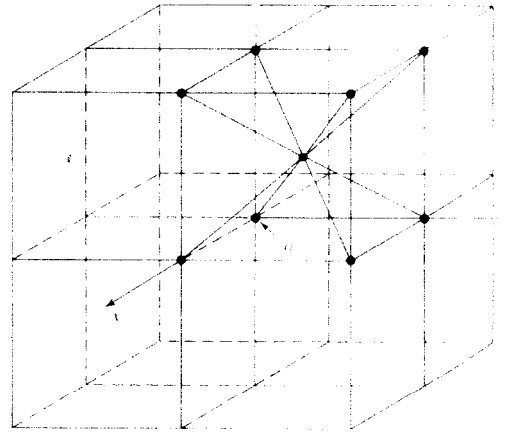
(a)



(b)



(c)



(d)

Figure 1.2 The structure of tungsten, BCC.

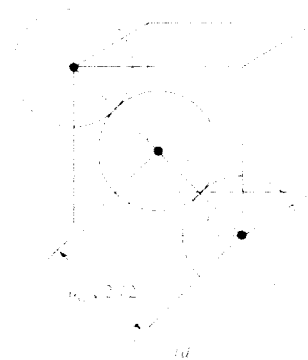
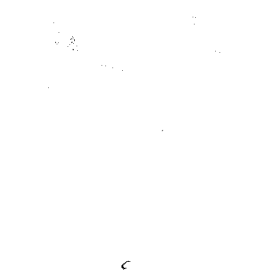
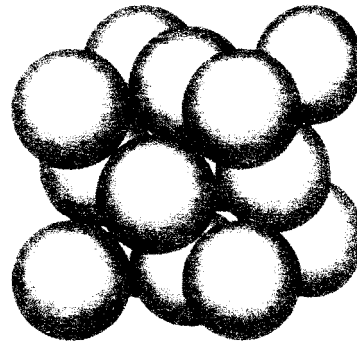
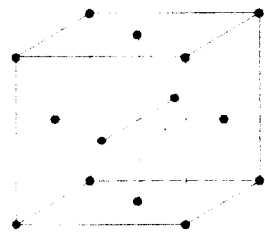


Figure - The structure of FCC

Co - ordination number:

The number of atoms touching a particular atom or the number of the nearest neighbors is the co- ordination number and is one in direction of how tightly and efficiently atoms are packed together.

Reference -

- 1 B.K.Agrawal, " Introduction to Engineering Material, TMH, 1988.
2. S H Avner; "Introduction to Physical Metallurgy", McGraw-Hill publications,

Experiment No. 2

Title: Study of the Metallurgical Microscope.

Objective: To study optical metallurgical Microscope and understand its working and associated terms.

Equipment: Optical metallurgical microscope.

Theory:

Metallurgical microscope is an instrument, which is capable of producing a magnified image of small object. It consist of a stand to which is attached a movable tube containing the optical parts of the microscope, and a device for illuminating the specimen.

Working principle:

Light from an electrical bulb on some suitable source falls on silvered portion of a semi-silvered glass plate kept at 45° to the vertical axis in the movable tube. These light rays get reflected vertically downwards, travel through the objective and fall on the specimen surface. The light rays reflected by the flat and polished specimen surface travel through the objective and transparent portion of the semi-silvered glass plate and come to the eyepiece.

In some of the microscopes, prism reflectors are used instead of semi-silvered glass plate in the vertical tube. The prism reflector is so positioned that only one half of the area of the objective operate is obstructed. The image can be focused on a screen and image can be observed.

Terms associated with microscope:

Magnifying power of an objective:

It is the ability of an objective to magnify the real object by a definite number of times without the aid of an eyepiece. This is engraved on the objective mount. Objectives are available with magnifying power of 5,10,40 or 45 or 100X(X sign denotes a linear magnification)

1. Magnifying power of an eyepiece:

It is ability of an eyepiece to magnify the real object by a definite number of times. This is printed on engraved on the eyepiece mount. Eyepieces are available with magnifying power of 5,6,7.5, 8, 10, 12, 15, 20 and 25X.

2. Vertical resolution of an objective:

It is the ability of an objective to produce sharply focused image when the surface of the object is not truly plane. This is also called as depth of focus on penetration. The vertical resolution is inversely proportional to the numerical aperture and the magnification of the objective and cannot be changed for a given objective. It is the order of 0.06 μm for oil immersion objectives.

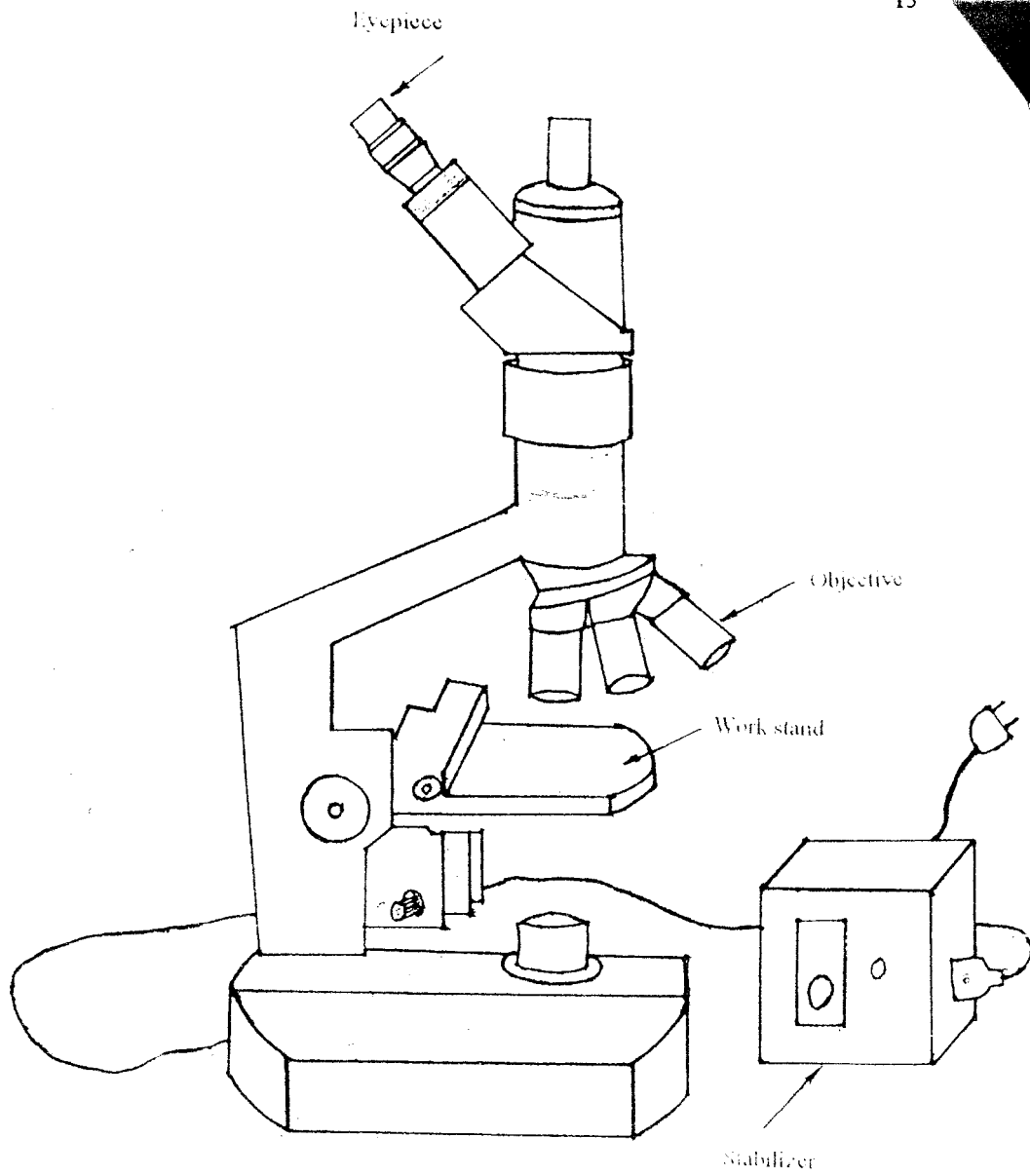


Figure 2.1 Metallurgical Microscope

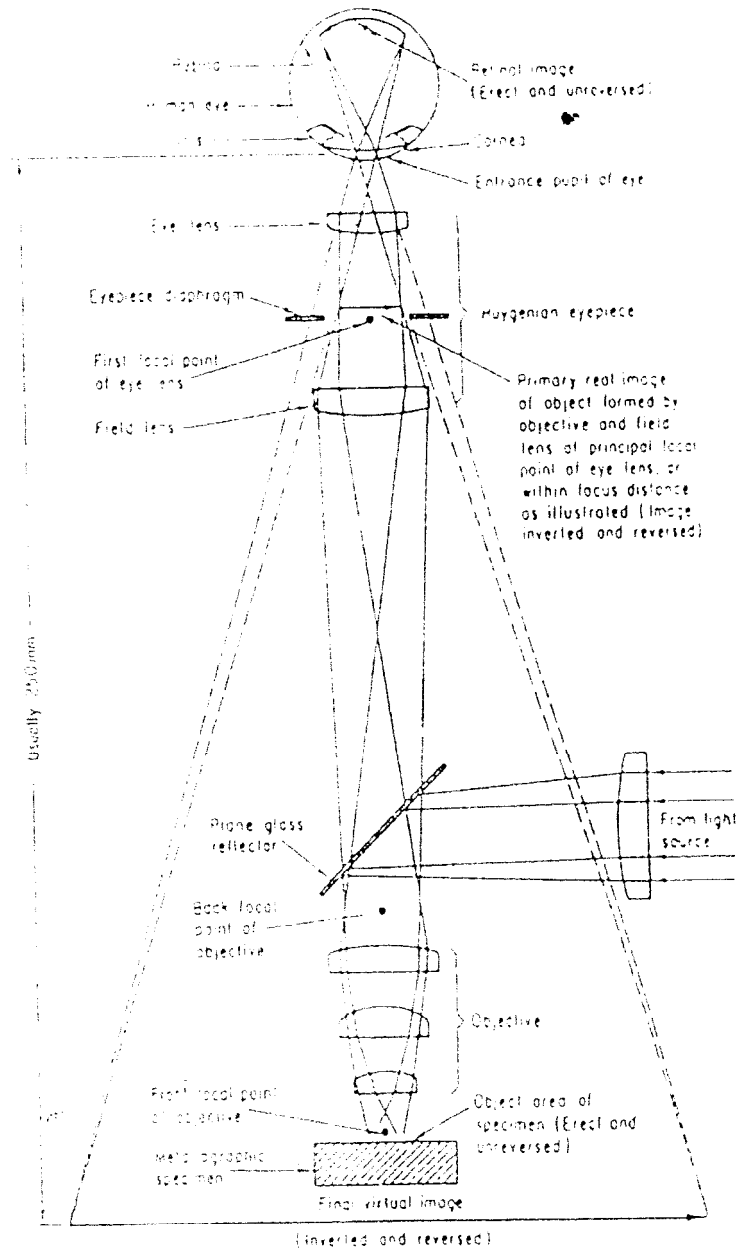


Figure 2.2 Principle of the compound metallurgical microscope

4. Numerical aperture of an objective:

It is light gathering or light collecting ability of an objective. It is constant for a given objective and is function of design.

Numerical aperture (N. A.) = $n \sin \theta$,

Where n = index of refraction, =1.0 (for air) θ = cone of light

5. Resolving power or resolution of an objective:

It is the ability of an objective to produce sharply defined separate images of closely spaced detail in the object. Fineness of detail or limit of resolution is the minimum distance (i.e. the linear which are at some minimum distance) that can be seen clearly and separately by that objective at some suitable magnification for narrow beam of light. Fineness of detail or resolution limit = $\lambda / \text{N.A.}$

Where λ = wavelength of illumination
N. A. — Numerical aperture of an objective.

Procedure:

1. Observe keenly the metallurgical microscope, its different parts and accessories.
2. Draw a neat line diagram of the microscope, label the parts.

Questions:

1. What is the difference between metallurgical microscope and biological microscope?
2. What do you understand by the following terms?
 - i) Numerical aperture of an objective, ii) Resolution
 - iii) Depth of focus. iv) Empty and useful magnification.

Exercise and assignment:

Collect information about the following:

1. Lens defects.
2. Various types of objectives and their functions:
3. Various methods of examination:
 - (i) Bright -Field illumination. (ii) Oblique illumination,
 - (iii) Dark-Field illumination. (iv) Polarized light

References:

1. Vander Voort; Metallographic: Principles and Practice; McGraw - Hill
2. ASM Handbook; Volume 1: Properties and Selection: Irons, Steels and High -Performance Alloys; ASM International.
3. Kehl George L; The principles of Metallographic Laboratory Practice; McGraw -Hill.

Experiment No. 03

Title: Preparation of the Specimen for the microscopic examination.

Objective: To understand the details of specimen preparation for observing the microstructure of mild steel.

Equipment: Abrasive cutting machine, power hacksaw, single disk polishing machine, double disk polishing machine, belt sander or abrasive belt grinder, mounting press, dryer.

Instruments: Thermometer, stopwatch.

Tools: Ball peen hammer, flat smooth file, polished papers of progressively finer grades (1/0, 2/0, 3/0, 4/0 grade or 120, 240, 320, 400, 600 and 800 mesh.), polishing cloth canvas, nylon, silk cloth (low nap or nap less)].

Materials: Mild steel, Bakelite powder, Lucite powder, cold setting resin and hardener.

Chemicals: Appropriate etching reagent: Nital [Nitric acid + Alcohol]
Nitric acid... 2 to 5 ml Ethyl or methyl alcohol.... 100ml

Theory:

Significance:

The specimen preparation steps for microscopy, often viewed as a tedious frustrating process, are of great importance since the true microstructure may be partially or fully obscured by poor technique or execution. Improperly prepared samples can lead to erroneous interpretations that can produce disastrous, expensive consequences. Success in microscopic study depends largely upon the care taken in specimen preparation. Even the most expensive microscope won't reveal the structure of specimen that has been poorly prepared. Micro structural details help to determine if the material has been processed correctly and thereby critically establishing the product reliability.

Purposes:

Structural details such as grain size; the size, shape and distribution of secondary phases and non-metallic inclusions; segregation and other heterogeneous conditions are revealed by microscopy. Study of micro structural details also reveal the history of mechanical and heat treatments given to the metal or alloy. All of them influence the mechanical properties and deformation behavior of metals. When these and other constitutional features are determined by Metallographic examination, it is then possible to predict the likely behavior of the metal for a particular service condition with reasonable accuracy.

Specimen preparation in brief:

1. Specimen selection:
Sectioning. Sampling.

2. Mounting: (optional)

Mechanical mounting, or
Hot and cold mounting, or
Cold mounting.

3. Grinding:

It consists of rough and fine grinding.

Rough:

For soft sample: flat smooth file.

For hard sample: belt sander.

Purpose is to make the surface flat, free from scratches.

Specimen is held perpendicular to grinding direction.

Fine:

Polished papers of progressively finer grades are used.

4. Polishing:

It consists of rough and fine polishing.

Rough:

Abrasive particle size 30-3um

Low nap or Naples cloth.

Fine:

Abrasive particle size 1 um and less.

Medium nap or high naps clothe.

5. Etching:

Using suitable etching reagents... does it (Nital in this case).

Procedure and Precautions:

Selecting a sample:

Decide the appropriate number of samples to be taken based on the size and complexity of the part and the nature of service condition. The number of samples must be just adequate to provide a statistically reliable description of material quality but not so extensive that test costs are excessive.

Based on the convenience in sectioning fix the location from which test sample it to be taken.

Preferably, systematic sampling is done to take care of the compositional gradients during solidification.

Fix the orientation of the section plane depending upon the manufacturing process of the sample, product shape, and features to be studied.

e.g.

In the casting, radial orientation i.e. parallel to the direction of solidification is preferred

In wrought materials longitudinal sections parallel to direction of rolling give idea about directionality and information about segregation and inclusion deformability.

In annealed components longitudinal section shows equi-axed grains.

Edges of the section must be preserved carefully to examine the carburization or Decarburization.

For surface defect examination a section through the surface layer is taken.

Sectioning the sample:

Preferably the specimen size should be 20 mm diameter or square.

Select the appropriate method of sectioning which must not alter the bulk structure e.g.

For brittle materials like carbides, ceramics, tools steels etc. fracturing by the blow of a hammer is used. Shearing is employed for low carbon steel sheet and foils and for thin and reasonably soft materials.

Take the carefully measured quantities of resin and hardener and thoroughly mix together.
Pour the mixture around the sample into the die.
Allow the resin to set for 15 to 20 minutes.
Take out the mount.

Mechanical mounting procedure:

In preparing transverse or longitudinal sheet surfaces, small rods, wires etc, mechanical mounting is very effective.

Specimens are coated with a layer of epoxy or lacquer in the clamp.

Spacers are used if the specimen surfaces are rough and are thin sheets of soft materials like copper, lead or plastic.

Coarse Grinding of the specimen:

For soft samples, use of flat smooth file is made.

For hard specimens, a belt sander is used.

Specimens should be moved perpendicular to the existing scratches so as to make specimen surface fiat and free of nicks, burrs etc. and remove the scratches due to previous operation.

While using the belt grinder:

Study the abrasive belt-grinding machine carefully.

Start the machine.

Hold the specimen or mount against the belt applying moderate pressure.

Frequently dip the specimen or mount in water to minimize the heat produced during the grinding.

Precaution: water should not be allowed to enter the roller, which may cause the slipping out of the belt from the rollers.

Fine Grinding of the Specimen:

Select the appropriate quality and type of abrasive papers.

Select the initial grit size of abrasive based on the surface roughness of the specimen and depth of damage during sectioning. Take 1/0 paper or 240 grit papers and keep it on flat surface.

Grind the specimen by applying moderately heavy pressure firmly and evenly.

Wash the specimen and then dry it.

Repeat the procedure on progressively finer grade papers i.e. on 2/0, 3/0, 4/0 paper or 320, 400 and 600 meshes.

Polishing of the specimen:

Using abrasive particle size in the range 30 to 3 um and canvas or nylon or silk clothe carry out the rough polishing.

Then, using abrasive particle size of 1 jam or smaller and low or medium or high nap cloth (selvyt, velvet, micro cloth, billiard) completes the fine polishing.

Maintain the dust free environment.

While using polishing machine:

Study carefully the constructional and operational features of the machine.

Remove the disc from the machine

Fit the appropriate cloth around the disc by using spring clamp.

Fit the disc on the machine.

Pour appropriate quantity of abrasive slurry on the disk

Switch on the machine [the speed should between 50 - 600 rpm]

For materials softer than 350 BHN, sawing is preferred.
When excellent quality of surface is required and a wide range of sample hardness is to be cut the most commonly used method is abrasive cutting. Silicon carbide wheels for non-ferrous metals and alumina wheels for ferrous metals are the appropriate choices.
Wire saws or wire EDM is used to produce damage free single crystal surface in electronics industry.
EDM is used in tool and die industry for cutting extremely hard electrically conductive materials.

While using abrasive cutting machine:

Study carefully various components and operational details of the machine.
Hold the specimen firmly in the vice and put the safety guard in position.
Switch on the machine and allow the wheel to attain its maximum speed of smooth rotation.
Start the coolant supply and ensure that it is directed towards the cutting region at constant flow rate.
Using the handle, slowly move the wheel downward on to the specimen to cut the required size.
Feed the wheel slowly and firmly towards the work piece.

Mounting the specimen: (optional)

Need: For small or oddly shaped specimens like wires, small rods, sheet metal specimens etc.
Mount size and shape should be decided by the size and shape of the part to be mounted.
Generally used mount size lies in the following range:
20-40 mm dia. and 10- 20 mm height
Select the proper mounting material and technique based on the following factors:
Mounting material and technique must not damage the specimen.
Mounting material must be resistant to attack by the etching reagents.

Hot mounting (Compression Mounting):

I. Thermosetting resin mounting

Requires heat and pressure during molding but no cooling is required for curing
e.g. phenolic plastic, bakelite.

Advantages:

- ✓ Available in powder form and in different colors.
- ✓ Resistance to attack by etchants is good.
- ✓ Less shrinkage.
- ✓ Softening due to heat is absent.

Disadvantages:

Cannot be used with thin and fragile specimen since both pressure and temperature is applied simultaneously.

II. Thermoplastic resin mounting:

Require heat and pressure during molding but must be cooled to ambient temperature under pressure for curing. e.g. transparent Lucite, polystyrene, PVC

Advantages:

Can be used with thin, fragile specimens since required pressure can be applied after the resin is molten.

Transparency: when grinding must be controlled to locate a particular defect or area of interest.

Disadvantages:

Softening due to heat

Shrinkage during cooling

Less resistance to strong etchants.

While using the mounting press:

Study the mounting press carefully and understand the operational and constructional features.

Unscrew the mold cap.

Raise the plunger inside the cylinder and keep the specimen on it facing smooth side towards plunger.

Lower the plunger (Ram)

Pour the calculated amount of resin powder inside the mould around the specimen.

Volume of powder = $\pi/4 \cdot D^2 \cdot H$.

Where, D = diameter of plunger (ram) = 22mm

H = mount height (10-20mm)

Press the plunger cap and fit the mould cap.

Switch on the power supply.

Apply the pressure hydraulically using a lever till the lever feels hard to move. Set the thermostat knob at appropriate units depending upon time required to attain the desired temperature.

e.g. if the thermostat knob is set at 80 units the time required to attain 100°C is 5 min.

Measure the temperature by touching the thermometer bulb to the cylinder just above the inlet coolant pipe head.

As soon as desired temperature is reached [e.g. 150° C for bakelite], switch off the supply.

Since temperature control is more critical than pressure control, minimum required temperature should be applied but should not be exceeded.

Again apply the pressure since the resin is molten.

Allow the mounting press to cool down for about 10-15 minutes naturally or using coolant depending upon the type of resin, e.g. for Bakelite, external cooling is not required. For Lucite, water-cooling is used.

Open the mould cap and raise the plunger to take out the mount.

Cold mounting: (Castable Mounting)

For quick mounting of thin, fragile and heat sensitive materials when good edge retention is not required

Mounting Materials: acrylics, polyesters, and epoxies. Hardener is required for setting.

Cold mounting procedure:

Apply grease on the flat surface of glass plate on which specimen is to be kept. Also apply grease to the inside of the cold setting die (ring) for easy removal of mount after setting.

Put the sample on the flat plate.

Keep the die (ring) over the sample.

Polish the specimen against the cloth by moving it from center to periphery of the wheel and against the direction of rotation.

Frequently clean the specimen between the polishing stages.

The pressure is moderately heavy during the initial polishing period and is gradually reduced toward the end.

Etching the specimen:

Select the proper etching reagent

Prepare the etchants as per the prescribed composition.

Clean the specimen surface by washing in water and dry it with the help of a dryer.

Smearing the surface with fingertip dipped in grit free soap solution and washing under tap.

Remove the final film of grease etc. by either immersion in boiling ethanol and cooling in water or by swabbing with a piece of cotton wool soaked in caustic soda solution. Apply the etchants either by immersion or by swabbing technique

For immersion etching, take the etchants in watch glass and immerse the polished surface of the specimen in it for specified period of time.

For swabbing technique cotton is wetted in the etchants and specimen surface is swabbed with it. It is preferred for those etchants with which the deposition of the reaction products or staining is problem.

Wash the specimen in running water and dry it evenly and quickly.

Observe the surface of specimen for knowing the completion of etching successfully.

Successfully etched surface appears slightly dull

Further etching for the surface appearing bright is carried out.

Procedure for specimen preparation of Mild Steel:

1) Sampling:

Cut the specimen using abrasive cut-off wheel.

Hold the specimen in vice.

Switch on the motor and start the coolant supply.

Using handle, slowly move the wheel downwards on to the specimen to cut the required size of material.

Use safety guard.

Precautions: Wheel may break if coolant pipe touches it or a very small bending force is applied.

2) Mounting:

Hot mounting is used for mild steel.

Raise the plunger inside the cylinder, keep specimen on it facing the smooth side towards the plunger and lower the plunger,

Pour the quantity of Bakelite powder inside the mould such that its volume is equal to $\frac{71}{4} \cdot D^2 \cdot H$ where, $D = 22\text{mm}$, $H = \text{mount height which is } 15\text{ mm}$, then

According to the above formula for volume we have:

$$\text{Volume (v)} = 5699.1 \text{ mm}^3$$

Press the cap and fit the cap screw,

Apply the pressure hydraulically to the plunger, till the pressure-applying lever feels hard,

The thermostat knob is set at 80 units. The time required to attain 100°C is 5 minutes

Measure the temperature by touching the thermometer bulb to the cylinder just above the inlet coolant pipe head.

As soon as desired temperature is reached i.e. 150°C , switch off the supply,

Since temperature control is more critical than pressure control, minimum required temperature should be applied but should not be exceeded,
Again apply the pressure since the resin is molten.
Let mounting press cool for 10 - 15 minutes.
Open the cap screw, cap nut and raise the plunger to take out the specimen.

3) Grinding:

Rough grinding on abrasive belt grinder

Switch on the electric supply.

Hold the mount against the belt, applying moderate pressure. The orientation of specimen should be such that the scratches produced during filing are perpendicular to the direction of belt movement,

Excessive pressure may produce deep scratches,

Frequently dip the specimen in water to remove the heat, which may alter the microstructure.

Precautions: Water should not come in contact with the belt.

Fine grinding on Sic papers

Take 1/0 Sic paper and keep it on a flat surface.

Grind the specimen in a direction perpendicular to previous scratches.

Repeat this for 2/0, 3/0, and 4/0 paper maintaining the same order.

4) Polishing:

Take out the disc from the machine.

Put the velvet cloth on it and fit it using the spring clamp.

Fit the disc on the machine.

Pour 4-5 drops of alumina slurry on the cloth.

Start the machine.

Polish the specimen on the cloth by moving the specimen from the center to the periphery in circular pattern, g. Continue the procedure till mirror like finish is obtained.

5) Etching:

Prepare the etchants (in this case Nital).

Take the etchants in watch glass and immerse the polished surface of specimen in it for specified time [30 seconds],

Wash the specimen thoroughly with water and dry it using dryer.

6) Observe:

Observe the specimen under the microscope using suitable magnification.

Questions:

1. Explain the significance of specimen preparation.
2. Mention the purposes of microscopy.
3. Discuss the factors affecting sample selection with suitable examples.
4. What are the various methods of sectioning the sample? Mention application of each.
5. Why mounting is required? Give examples.
6. Mention the typical range of mount size and the factor affecting the same.
7. What are the requirements of mounting material and technique?
8. Give advantages and limitations of thermosetting and thermoplastic resin mounting.
9. When is cold mounting preferred? Why?
10. Name the different kinds of abrasives used in fine grinding with their specific uses.
11. Mention the factors deciding the initial grit size of abrasive.
12. Why coolant is used during grinding and polishing?
13. Explain the etching mechanism for single phase and double phase alloys.
14. When is swabbing method of etching preferred? Give applications.

Exercises and Assignments:

1. Collect the data about melting point of various mounting materials.
2. Prepare the chart of etching reagents with respect to composition, application and time of etching.
3. Discuss various defects in cold mounting and hot mounting and their causes and remedies.
4. Prepare the mechanical mounting clamp.
5. Prepare the specimens of sheet metal and Cu-wire.
6. Prepare the list of various cloths and their applications.

References:

1. Vander Voort; Metallographic: Principles and Practice; McGraw - Hill
2. ASM Handbook; Properties and Selection of — Irons, steels and high — performance alloys (Vol. 1); ASM International.
3. Kehl George L.; The Principles of Metallographic Laboratory Practice; McGraw -Hill.

Experiment No. 4

Aim: Mounting of the specimen in a plastic mould.

Principle: Metallographic specimens, which are too small or too awkward in shape, like chips, wires, sheet metal specimens and thin sections are mounted in a suitable plastic for convenient handling during polishing.

Units Used: Specimen, Cold setting die set, resin solution.

Procedure:

Thermosetting or thermoplastic type polymers are used for mounting of specimens. Bakelite moulding powder is available in variety of colors, which helps in identification of specimens and hence commonly used for hot mounting of specimens.

For certain heat - treated alloys', heating is not permissible because of the possibility of change of structure and hence this method of mounting is not suitable for such alloys. Also, this method is not suitable for low melting point non-ferrous alloys. Therefore for such metals and alloys, cold mounting method is used; the procedure of which is as below.

The specimen is kept on a glass plate and a metal tube of suitable size is placed around the specimen. A polymeric solution is poured in to this tube. This solution polymerizes and becomes hard like cement in 10 to 15 minutes. After complete setting, sample along with mount is taken out from the tube. For easy removal of mount grease can be applied on glass plate and to the inner surface of the tube. Tubes are of different diameters and lengths, and can be of copper, brass, bronze or steel. A proper sized tube should be used for economy of cold setting medium.

Experiment No. 5

Title: Study of the microstructures of the plain carbon steels.

Objective: To study and draw the microstructures of mild steel, medium carbon steel, eutectoid steel and hypereutectoid steel.

Equipment: Optical Metallurgical Microscope.

Materials: Prepared specimens of mild steel, medium carbon steel, eutectoid steel and hypereutectoid steel.

Theory:

General features of Microstructures:

- Gives details about grains of single-phase metals and alloys.
- Shows shapes and sizes of grains of micro-constituents and their configurational arrangements in case of multi-phase systems as they produce a variety of typical microstructures.

In the Fe-Fe₃C (Iron - Iron Carbide) equilibrium diagram, the eutectoid transformation takes place at a temperature of 727°C and at 0.8%C. In eutectoid transformation; austenite decomposes and forms mixture of ferrite and cementite, which is called pearlite. i) Steels containing carbon from 0.008%C to 0.8%C are called **hypo-eutectoid steels**, ii) Steels containing 0.8%C are called **eutectoid steels**, iii) Steels containing 0.8%C to 2.0%C are called **hyper-eutectoid steels**.

Various Phases in Slowly Cooled Steels:

I. Hypo - Eutectoid Steels:

These steels contain carbon from 0.008%C to 0.8%C. For better illustration of changes in structures during cooling of steels from austenite region, the eutectoid region of Fe-Fe₃C diagram is shown separately.

Structural changes for mild steel (0.2% C) and medium carbon steel (0.5% C) are as follows

At point 1, α -ferrite starts separating out at grain boundaries of austenite (γ). As the temperature decreases, the amount of α -ferrite increases. The composition of α -ferrite varies along the line CB and that of austenite (γ) along the line CE. This continues up to point 2. The amount of α -ferrite and austenite (γ) at any temperature between points 1 and 2 can be found out by applying the lever rule. This α -ferrite, which has separated before eutectoid transformation (i.e. at point temperature) is called the primary- α or free α or proeutectoid- α (*pro* means before).

At point 2, the existing austenite (γ) transforms at constant temperature of 727°C to a mixture of ferrite and cementite called pearlite by eutectoid transformation process.

Cooling from 2 to 3 doesn't result in significant changes in the microstructure due to insignificant solubility of carbon in α and hence same structure is observed at room temperature.

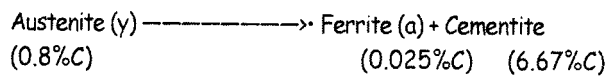
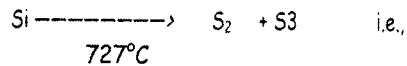
For other steels, the sequences of structural changes are very much similar as above but only the amounts of phases that will be present are different. As the percentage of carbon goes on increasing, the amount of pro eutectoid ferrite decreases and pearlite increases. For 0.8%C, the amount of pro eutectoid ferrite becomes equal to 0% and pearlite becomes 100%. There is a linear variation in carbon

content of steels and amount of ferrite and pearlite. For 0.008%C, the amount of α is 100% and 0.8%C the amount of pearlite is 100%. This means that every 0.1%C approximately corresponds to 12.5% pearlite.

Ferrite appears white and pearlite appears dark under microscope with most common etchants such as Nital or picral.

II. Eutectoid Steels:

In general, eutectoid transformation is denoted as: -
Constant



Austenite of 0.8%C decomposes at constant temperature of 727°C and forms a mixture of ferrite and cementite. This mixture of ferrite and cementite is called pearlite due to pearly appearance under optical microscope. It consists of alternate lamellae of ferrite and cementite. Austenite has FCC structure whereas ferrite and cementite have BCC and Orthorhombic structures respectively.

Hyper - Eutectoid Steels:

These steels contain carbon between 0.8%C - 2.0%C. The structural changes of steel with 1.4%C are described here as follows: -

1. At point 1, Fe₃C starts separating out along the grain boundaries of austenite (γ). As the temperature decreases the amount of cementite increases and austenite decreases. The composition of austenite varies along the line DE and the composition of cementite does not change, since it is an inter metallic compound. This continues up to point 2. The amounts of austenite and cementite can be found out by applying the lever rule. This cementite, which has separated before the eutectoid transformation is called primary, free, or proeutectoid cementite.

2. At point 2, existing amount of austenite transforms at constant temperature of 727°C to pearlite.

3. Cooling from 2 to 3 does not result in significant change in microstructure and same microstructure is obtained at room temperature.

Free cementite increases linearly with increasing carbon and for 2.0% carbon steel its value is 20.4%. Every 0.1% C approximately corresponds to 1.7% cementite.

Procedure:

1. Clean the objective and the eyepiece of the optical metallurgical microscope.
2. Take the prepared specimens.
3. Place them one by one under the optical metallurgical microscope.
4. Observe the microstructure of each of the specimens carefully.

Structural Changes:

A] Structure-Property Relationship In Hypo-Eutectoid Steels:

The microstructure of hypo-eutectoid steels slowly cooled from austenite temperature shows the grains of ferrite and pearlite.

As the percentage of carbon increases amount of ferrite decreases and that of pearlite increases. Ferrite being a soft phase and pearlite the hard phase the elongation decreases with increase in tensile strength and hardness, as the carbon percentage increases.

B] Structure-Property Relationship In Eutectoid Steels:

From the amount of ferrite and cementite it is seen that ferrite lamella is 7.4 times thicker than cementite lamella. The properties of pearlite depend upon its inter-lamellar spacing. If inter-lamellar spacing is smaller, stronger are the mechanical properties. The inter-lamellar spacing depends on the cooling rate and within limit; the spacing becomes less and less with increasing cooling rate. The hardness of pearlite, for practical purpose, is taken as 250 BHN.

Applications:

Band screws, anvil faces, hammers, wrenches, laminated springs, car bumpers, cable wires, dies, cold chisels, blades, punches, rock drills, etc.

C] Structure-Property Relationship In Hyper-Eutectoid Steels:

The microstructures of hypereutectoid steels slowly cooled from the austenitic region will show continuous network of cementite across the boundaries of pearlite regions. Cementite is a hard phase and hence it does not allow moving the dislocations from region to region via boundaries. Therefore, such steel becomes more brittle and does not serve the purpose. So the slow cooling of these steels deteriorates the properties of steels. Hence such structures are rare in commercial products.

Applications:

Used for saws, rotors, finishing tool where high resistance to wear is essential.

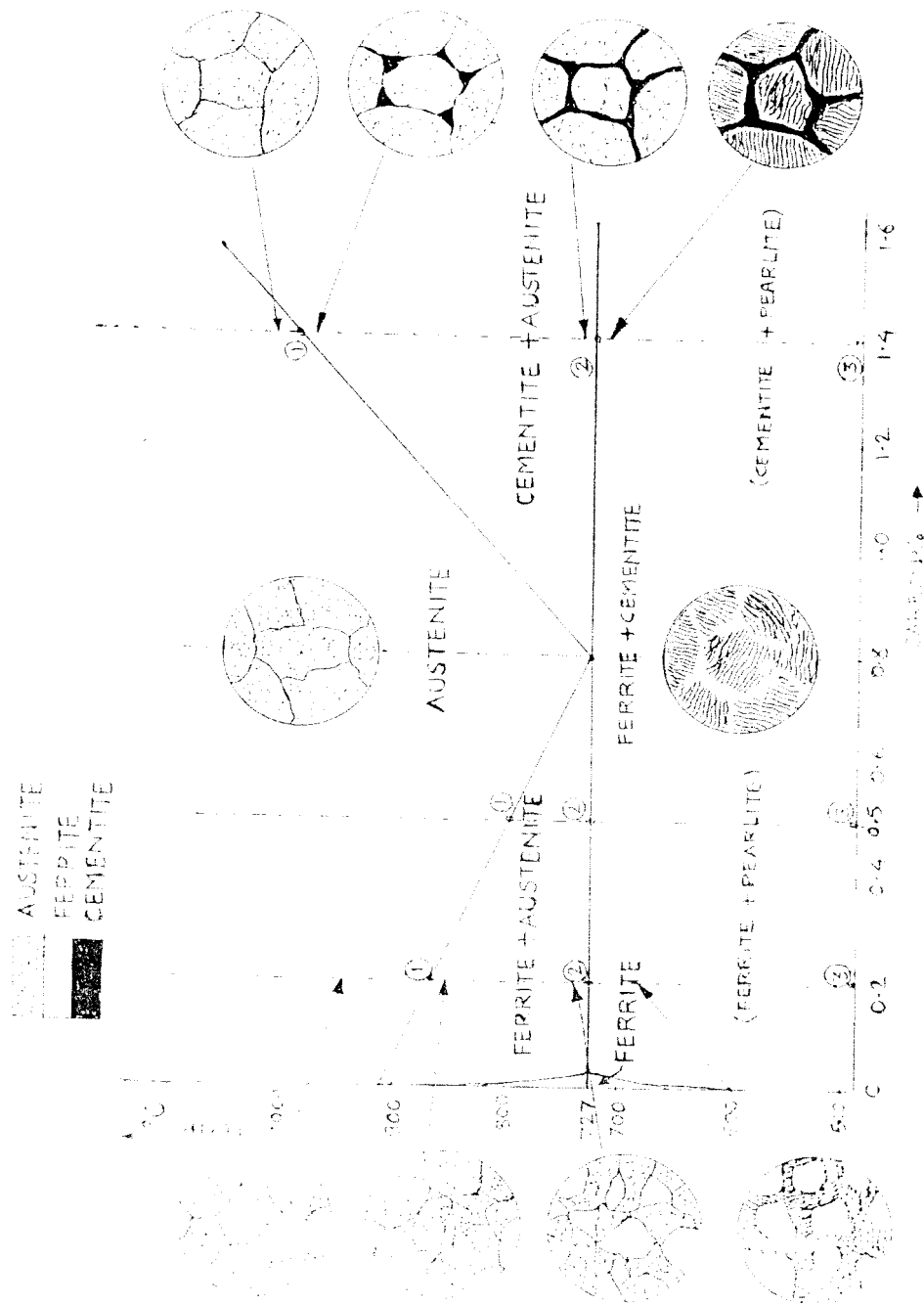
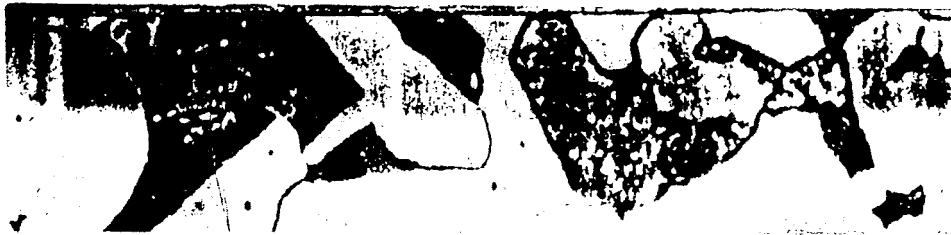


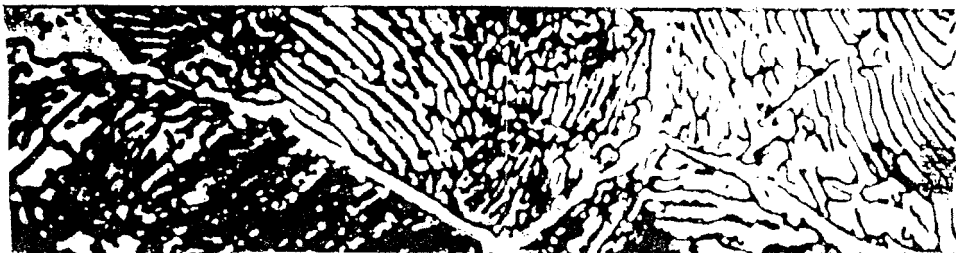
Figure 5.1 Part of Iron Carbon diagram



0.2 % C Mild steel



0.5 % C Medium carbon



0.8% C Eutectoid steel



1.4% C Hypereutectoid steel

Figure 5.2 Microstructures of various steels

Structural Changes:

1. Microstructure of White cast iron consists of pearlite, cementite and ledeburite. Microstructure of hypoeutectic cast iron ($C > 4.3\%$) shows pearlite, cementite and small amount of ledeburite. Microstructure of hypereutectic cast iron shows ledeburite and cementite plates.
2. Microstructure of Malleable cast iron shows graphite nodules called temper carbon, uniformly distributed in ferritic-pearlitic matrix.
3. Microstructure of Pearlitic gray cast iron shows graphite flakes in pearlite matrix.
4. Microstructure of Nodular cast iron shows nodules or spheroids of graphite in pearlitic matrix.

Procedure:

1. Put the prepared specimen on the stage of microscope.
2. Switch ON the power supply.
3. Select the eyepiece lens depending upon the magnification required.
4. Make the microstructure visible with coarse adjustment screw of microscope.
5. Make the microstructure fine with help of fine adjustment screw.
6. Observe the microstructure carefully and identify the phases.
7. Draw the microstructure.
8. Repeat the same procedure for other specimens.

Questions:

1. Describe grades of gray cast iron.
2. What are relative advantages of gray cast iron over other types of irons?
3. Nodular cast irons possess wide range of mechanical properties, then why are other types of cast iron produced?
4. Mention at least two advantages of malleable cast iron over nodular cast iron?
5. Why malleable cast irons cannot be rolled in thin sheets?

References:

1. Dr. V. D. Kodgire; Material Science and Metallurgy for Engineers; Everest Publishing House.
2. B. K. Agarwal; Introduction to Engineering Materials; Tata McGraw-Hill Publication Company Limited, New Delhi.

Experiment No. 6

Title: Study of the microstructures of the alloy steels.

Objective: To study and draw the microstructures of alloy steels.

Equipment: Optical Metallurgical Microscope.

Materials: Prepared specimens of alloy steels.

Theory:

Alloy steels:

The main constituents of plain carbon steel are iron and carbon. The properties of carbon steels are directly related to the percentage of carbon present. In addition to carbon, plain carbon steels also contain other elements such as, manganese, silicon, sulphur and phosphorus in the amounts shown in table.

These elements do not have an appreciable effect on the properties of carbon steels. Carbon is responsible for the required hardness and strength in the steel. Manganese is present to provide a minimum hardenability and strength after working. Silicon and phosphorus are present as unwanted impurities.

Alloy steel may be defined as carbon steel to which one or more elements are added to get some beneficial effects. The commonly added elements include silicon, manganese, nickel, chromium, molybdenum, tungsten, vanadium, copper, boron, aluminium, etc. Due to the presence of these elements, alloy steels possess the following improvements in properties and applications as compared to carbon steels.

- i) Alloy steels can have higher hardness, strength and toughness.
- ii) High hardness and strength values can be achieved in much higher cross sections in alloy steels, as compared to plain carbon steels.
- iii) They possess much higher hardenability, which has a great significance in heat treatment.
- iv) Alloy steels have higher temperability, and they retain their hardness and strength at elevated temperatures (cross strength), as compared to plain carbon steels.
- v) They possess high hardness (red hardness) at temperatures up to 600 °C, due to the presence of alloy carbides.
- vi) Alloy steels have higher corrosion and oxidation resistance.

Effects of alloying elements:

Alloying elements can affect the constitution, characteristics, and behavior of in many ways. Some of the major effects of alloying elements are, strengthening of ferrite, formation of special carbides and compounds, shifting of critical temperatures and compositions, and lowering of critical cooling rate.

Functions and uses of alloying elements:

Alloying elements, when added to steel, perform different functions depending upon their characteristics, amounts, and the subsequent heat treatment. Some of the important functions and applications of different alloying elements are given below.

Sr. No.	Alloying elements	Typical range (percent)	Principal functions
1	Sulphur	<0.33	Improves machinability, reduces weld ability and ductility.
2	Phosphorus	<0.12	Improves machinability, reduces impact strength at lower temperatures.
3	Lead	<0.35	Improves machinability
4	Silicon	0.2-2.5	Removes oxygen in steel making. Improves toughness. Increases hardnability.
5	Manganese	0.2-2.5	Increases hardnability. Combines with sulphur to reduce its adverse effects.
6	Nickel	0.3 - 5.0	Increases hardnability. Increases toughness. Increases impact strength at lower temperatures. Promotes an austenite structure.
7	Chromium	0.3- 4.0	Increases resistance to corrosion and oxidation. Increases hardnability. Increases high temp. Strength. Combine with carbon to form hard and wear resistant to carbides.
8	Molybdenum Or Tungsten	0.1 - 0.5	Inhibits grain growth at high temperatures. Increases hardnability. Forms carbides having high red hardness and wear resistance. Enhances the effect of other alloying elements. Eliminates temper brittleness in steels. Improves high temperatures strength.
9	Vanadium	0.1 - 0.3	Increases hardnability. Inhibits grain growth at high temperatures. Forms carbides possessing highest hardness and wear resistance. Improves fatigue resistance
10	Aluminium	<2	Forms nitrides in nitrating steel. Produces fine grain size in castings. Removes oxygen in steel melting.
11	Cooper	0.2- 0.5	Improves atmospheric corrosion resistance.
12	Boron	< 0.005	Increases hardnability. Produces fine grain size.
13	Titanium	<1.0	Strongest carbide former. Added to stainless steels to prevent precipitation of chromium carbide.

TYPICAL EXAMPLES OF ALLOY STEELS:

- 1) Free cutting steels
- 2) Structural steels
- 3) Rail steels
- 4) Spring steels
- 5) Weldable steels
- 6) Concrete reinforcing steel
- 7) Creep resisting steel
- 8) High speed steel
- 9) Ball bearing steels
- 10) Maraging Steels
- 11) Hadfield manganese steel
- 12) HSLA steels
- 13) Dual phase steels

Questions:

1. What is alloy steel? Why is it so called? What is the range of composition of alloy steels?
2. Name three most important properties of alloy steels as compared to carbon steels.
3. What is the difference between impurities and alloying elements? Name a few impurities present in steel
4. How does the addition of an alloying element improve the properties of steel ?
5. Which elements form carbides? What role do carbides play in alloy steels?
6. Nickel and chromium are universally added to constructional steels. What role do they play in these steels?
7. Manganese is found in most of alloy steels. Name two most important functions of manganese in these steels.
8. Name two alloy steels where aluminium is added as an alloying element. What is the role of aluminium in these steels?

Procedure:

1. Clean the objective and the eyepiece of the optical metallurgical microscope.
2. Take the prepared specimens.
3. Place them one by one under the optical metallurgical microscope.
4. Observe the microstructure of each of the specimens carefully.

References:

ASM Handbook; Metallography and Microstructures (Vol. 9); ASM International.
Introduction to engineering materials by B. K. Agarwal Tata McGraw Hill Co. Ltd.

Questions:

1. "Hyper-eutectoid steels show pro-eutectoid ferrite in their structures at room temperature". Do you agree with this statement? Justify.
2. Define the following structural components and give the maximum solubility of carbon in each and also identify whether it is a phase or a mixture? i. Ferrite ii. Pearlite iii. Cementite iv. Austenite
3. Why solubility of carbon is more in austenite than in ferrite? Explain with sketches.
4. What are the micro structural phases of hypo eutectoid and hypereutectoid steels?
5. Write the composition of Nital and picral?
6. How will you justify the fact that every 12.5% proeutectoid ferrite in hypo eutectoid steels and 1.7% proeutectoid cementite in hypereutectoid steels corresponds to 0.1% C?
7. Which factors are to be considered while relating microstructure with mechanical properties?
8. Draw Fe-C equilibrium diagram and label the temperatures, compositions and phases?
9. Explain following with neat sketch:
 - i. Pearlitic transformation
 - ii. Eutectic transformation
 - iii. Eutectoid transformation
10. What is steel? What is mean by eutectoid, hypo-eutectoid and hyper-eutectoid steels?
11. Which steels show Pearlitic transformations? Which steels do not show pearlitic transformations?
12. Name three allotropic forms of iron and indicate the crystal structure of each.
13. A slowly cooled steel contains 60% ferrite and 40% pearlite at room temperature, determine amount of total ferrite and cementite present in the alloy.
14. Determine the amounts of following phases present in 1.1% C steels under equilibrium conditions,
 - i. Austenite and cementite just above eutectoid temperature.
 - ii. Proeutectoid cementite, pearlite and total cementite at room temperature.

References:

1. S H Avner; Introduction to Physical Metallurgy; McGraw Hill Publications.
2. Vander Voort; Metallography: Principles and Practice; McGraw Hill Publications.
3. Alok Nayar; The Steels Handbook; Tata McGraw Hill Co. Ltd.
4. ASM Handbook; Metallography and Microstructures (Vol. 9); ASM International.

Experiment No. 7

Title: Study of the microstructures of the cast irons.

Objective: To study and draw the microstructures of the microstructures of white cast iron, gray cast iron, malleable cast iron, and nodular cast iron.

Equipment: Optical Metallurgical Microscope.

Materials: Prepared specimens of white, gray, malleable and nodular cast iron.

Theory:

Cast irons are the alloys of iron and carbon (carbon between 2.0% to 6.67%).

Types of cast iron on the basis of microstructure

1. White cast irons
2. Malleable cast irons
3. Gray cast irons
4. Nodular cast irons
5. Mottled cast irons
6. Chilled cast irons
7. Alloy cast irons

Microstructure of cast irons are influenced by

- I. Amount of total carbon
- II. Amount of silicon
- III. Amount of Phosphorus
- IV. Amount of sulphur
- V. Amount of manganese
- VI. Cooling rate

1. White cast iron:

Method of manufacturing:

a. Microstructure of hypoeutectic white cast iron:

- From 1 to 2, the alloy is in liquid state and there is no change in state.
- Just below 2, austenite starts separating out from liquid up to 3. This proeutectic austenite is in dendritic form and is separating out from the liquid state.
- At 3, above liquid solidifies at constant temperature of 1147°C and forms an eutectic mixture of austenite and cementite called ledeburite.
- From 3 to 4, there is no change in morphology of structure, due to rejection of Fe₃C by primary eutectic austenite, amount of Fe₃C increases and separates out from point 3 to 4 called as proeutectic cementite.
- At 4, primary and eutectic austenite transforms to eutectoid mixture of ferrite and cementite at 727°C temperature.

- From 4 to 5, there is no change in microstructure except slight increase in amount of Fe_3C .
- At room temperature microstructure consists of dendritic area of transformed austenite i.e. pearlite in a matrix of transformed ledeburite.

b. Microstructure of eutectic white cast iron:

- Liquid alloy solidifies at eutectic temperature of 1147°C by an eutectic transformation process and gives a mixture of austenite and cementite.
- Further cooling from 1147°C to 727°C there is no change in morphology of structure. Only increase in amount of Fe_3C due to separation of proeutectoid Fe_3C from eutectic austenite because of decrease in solubility of carbon in austenite.
- At eutectoid temperature of 727°C austenite transforms to pearlite.
- Cooling from 727°C to room temperature slightly increases the amount of cementite.
- At room temperature microstructure shows cementite and pearlite called ledeburite.

c. Microstructure of hypereutectic white cast iron:

- Microstructure of this cast iron is similar to that of hypoeutectic cast iron except that, proeutectic phase separates out from liquid being cementite instead of austenite.
- At room temperature the microstructure shows, dendrites of primary cementite in the matrix of ledeburite.

Composition:

C - 2.5 to 3% Si-0.5 to 1.3% S-
0.06 to 0.1% P-0.1 to 0.2%
Mn- 0.5 to 1.0%

Properties:

1. White cast irons are hard (350 to 500 BHN) and brittle. Hardness increases with increase in C percentage.
2. They are strong in compression (150 to 175 kg/mm^2).
3. Resistant to abrasive wear.
4. Difficult to machine.

Applications:

White cast irons are used for wearing plates, road roller surfaces, pump liners, mill liners, grinding balls, dies extrusion nozzles.

2. Malleable cast irons:

Method of Manufacturing:

Malleable cast irons are produced from white cast iron casting by Malleablizing heat treatment. The structure of cast iron consists of austenite and cementite of which cementite decomposes to austenite and graphite at 900°C . This graphitization of cementite gives irregular nodules or spheroids called rosettes of temper carbon graphite

- At point 2, the structure shows rosettes of temper carbon graphite in a matrix of austenite.
- After cooling to room temperature i.e. at point 3 austenite transforms to pearlite so microstructure shows rosettes of temper carbon graphite in the matrix of pearlite.
- But if the cooling rate is slow or percentage of silicon in white casting is more, cementite from pearlite decomposes to ferrite and graphite, and microstructure at 3 shows rosettes of temper carbon graphite in the matrix of ferrite.

Types of Malleable cast irons:

- a. Ferritic malleable
- b. Pearlitic malleable
- c. Pearlitic - Ferritic malleable
- d. Black heart malleable
- e. White heart malleable

Composition:

C - 2.0 to 3.0% Si-0.9 to
1.65% P and S< 0.18% Bi and
B< 0.01%

Properties:

1. Malleable cast irons show some ductility, toughness
2. Other properties

T.S	-	25 to 70 kg/mm ²
Elongation	-	6 to 18%
Hardness	-	80to275BHN

Applications:

- For components requiring some ductility and toughness e.g. pipe fitting, valves, automotive parts, chains etc.
- For manufacturing crankshafts, axles, gears, links and ordinance parts.
- Also used for electrical applications.

3. Gray cast irons:

Method of manufacturing:

Manufactured by cooling slowly the liquid alloy of suitable composition usually in sand moulds. During slow cooling cementite is decomposed into iron and carbon. The composition of the alloy is adjusted in such a way that all the proeutectic (from hypereutectic alloys) and eutectic cementite decomposes as soon as it forms and eutectoid cementite does not decompose which is done by controlling the amount of carbon and silicon in the alloy. If amount of these two elements is more, eutectoid cementite may also decompose with the normal cooling rates as encountered in sand moulds. A control over the composition must be exercised in such a way that all the proeutectic and eutectic cementite must decompose-obviously this leads to the decomposition of all proeutectoid cementite and no eutectoid cementite should decompose.

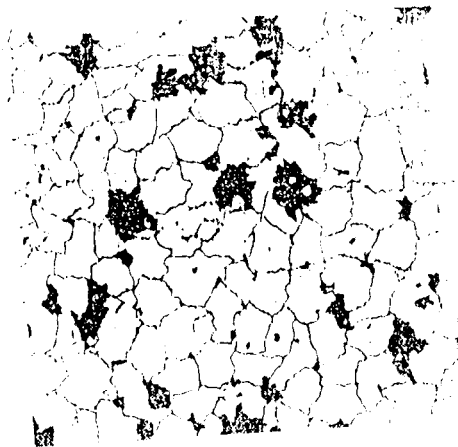
This is necessary to obtain a pearlitic matrix in gray cast irons, which can also be controlled by controlling the cooling rate through eutectoid transformation region.

Control of flake size:

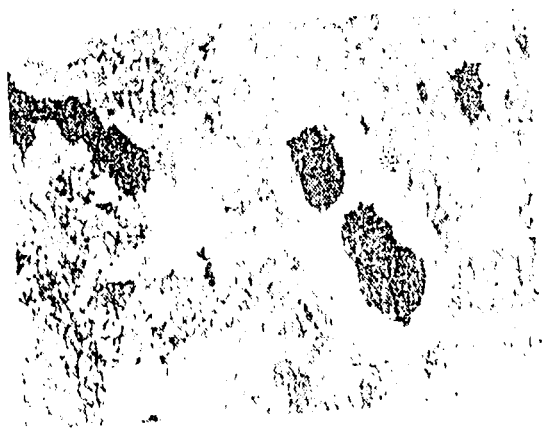
Cast irons contain graphite in the form of flakes. To reduce size and improve distribution of graphite flakes, small amount of material called inoculants are added. Inoculants like calcium silicate, silicon carbide, metallic calcium, aluminum, titanium, zirconium, or combination of these. The inoculating agent might be increasing nucleation rate giving a fine grain size of austenite or it must be momentarily displacing the eutectic point to the left i.e. towards low carbon side so that a hypoeutectic cast iron will solidify as an eutectic cast iron, eliminating primary austenite crystals.



Pearlitic



Ferritic



Bull's eye

Figure 7.1 Microstructures of Cast Iron

Composition:

C - 3.2 to 3.7% Si - 2.5 to 3.5% S-0.06 to 0.1% Mn- 0.5 to 1.0%

Properties:

1. Excellent, machinability
2. Good compressive strength
3. Good bearing properties
4. Fairly good corrosion resistance
5. Other properties
T.S.-15to40kg/mm² Hardness - 150 to 300 BHN Elongation - less than 1%

Applications:

- Used as a base for erection of machinery.
- Used for engine frames, drainage pipes, elevator and industrial furnace, counter weights, pump housings etc.

4. Nodular cast irons:**Method of manufacturing:**

Nodular cast irons are produced from gray cast iron by the addition of small quantity of certain elements called as nodulizing elements such as magnesium, cerium, calcium, barium, lithium or zirconium. Most commonly the addition of Mg (0.06% to 0.08%) is done to the gray cast iron melt usually in the ladle just prior to pouring in to the moulds. Any delay in pouring results in the distortion of nodular shape of a graphite and resulting reduction in properties of these cast irons. Re melting of nodular cast iron produces gray cast iron, unless fresh nodulizing addition is done.

When nodulizing element is added to the molten bath and stirred, large amount of gas is evolved also gets dissolved in the melt. This dissolved gas gives rise to large number of blowholes in the solidified casting. Also, the contraction of nodular cast iron during freezing is considerably greater than that of ordinary gray cast iron. Due to this, careful design of the mould is necessary to avoid shrinkage cavities in solidified casting.

Composition:

C-3.2 to 4.1% Si-1 to 2.8%
S < 0.03% P<0.1% Mg-0.05 to 0.1%

Properties:

1. High tensile strength, ductility and toughness.
2. T. S. -38 to 80 kg/mm².
3. Elongation - 6 to 20%.
4. Hardness-100 to 300 BHN.

Applications:

- For crankshafts, gears, punch dies, sheet metal dies, metal working rolls, furnace doors, pipes, pistons, cylinder blocks and heads and bearing blocks.

EXPERIMENT NO: - 08

Title: Study of the microstructures of the Non-ferrous alloys.

Objective: To study and draw the microstructures of α -brass, α - β brass, aluminum bronze, tin-bronze and a bearing metal.

Equipment: Optical Metallurgical Microscope.

Materials: Prepared specimens of α -brass, α - β brass, aluminum bronze, tin-bronze and a bearing metal.

Theory:

I. Brasses

i. Manufacturing:

- Brasses are essentially alloys of copper and zinc.
- Equilibrium diagram of Cu-Zn system is shown in [Fig. 6.1].
- The equilibrium solubility of zinc and copper is around 38% and is influenced by cooling rate. Normally in practice solubility limit is 30%.
- If the zinc addition exceeds solubility limit, a second phase beta (P) is formed. Beta (8), intermediate phase exhibits order-disorder transformation between 453°C and 470°C. Below this temperature, the structure of beta (3) is ordered (indicated as 8') and above this it is disordered. With more than 50% of zinc another phase gamma (γ) is formed.

The mechanical properties of brasses depend on the amount of zinc in the alloy. It is shown in the following table [Fig. 6.1].

Zinc, %	Tensile strength, (MPa)	Elongation, %	BHN
0	220.7	46	38
5	248.2	49	49
10	282.7	52	54
15	289.6	56	58
20	296.5	59	56
25	310.3	62	54
30	317.2	65	55
35	317.2	60	55
40(8')	372.4	45	70

Classification:

The commercial brasses may be divided in two groups

- a) Brasses for cold working (α brass)
- b) Brasses for hot working (α - β brass)

1. α -Brasses:

They are sub classified as follows:

- Cap Copper
- Gilding Metals
- Cartridge Brass Admiralty Brass

2. α - β Brasses:

They are sub classified as follows:

- Muntz Metal
- Naval Brass
- Leaded Brass
- High Tensile Brasses Brazing Brass

I. α - Brasses:

i) Composition: 36% Zn, 64% Cu.

ii) Properties:

1. Good corrosion resistance.
2. Soft, ductile, malleable.

iii) Applications: Suitable for cold working, wire drawing, presswork.

Types of α -Brasses:

a. Cap Copper

i) Composition: 95-98% Cu, 2-5% Zn.

ii) Properties: Ductile and malleable.

iii) Applications: Used for caps of detonators in ammunition factories.

b. Gilding Metals

i) Composition: 85-95% Cu, 5-15% Zn.

ii) Properties: They have different shades of colors depending on zinc percentage.

iii) Applications:

1. Bullet envelopes
2. Drawn containers, condenser tubes, coins, and needles.
2. Dress jewellery because of color like gold.

c. Cartridge Brass

i) Composition: 70% Cu, 30% Zn.

ii) Properties: It has maximum ductility and malleability amongst all the brasses

iii) Applications: Used for forming by drawing, stretching, trimming, and spinning and Presswork operations.

1. Cartridge cases
2. Radiator fins
3. Lamp fixtures
4. Rivets and springs

d. Admiralty Brass

i) Composition: 76% Cu, 22% Zn, 2% Al

ii) Properties: Good corrosion resistance.

iii) Applications:

- a. 69% Cu, 30% Zn, 1% Sn is used for condenser tubes and heat exchangers in steam power plants. *
- b. 76% Cu, 22% Zn, 2% Al is used widely for marine applications.

II. α - β Brasses

i) Composition: 60-68% Cu, 32-40% Zn

ii) Properties:

1. Hard and strong as compared to α -brasses.
2. These two phase alloys become single-phase beta (β -distorted) alloys at higher temperature. Disordered beta (β') has more ductility and malleability as compared to ordered beta (i.e. β). Therefore, α - β brasses are hot worked at a temperature of about 600°C. Their corrosion resistance is poor compared to alpha (α) brasses.

iii) Applications: Suitable for casting purposes.

Types of α - β Brasses

a. Muntz Metal

i) Composition: 60% Cu, 40% Zn.

ii) Properties: The alloy becomes single phase at about 700°C. It can be hot worked, extruded or rolled in the temperature range of 600°C - 800°C. Hot worked 60-40 brass shows a tensile strength of 35-40 kg/mm² and hardness of 100-120 VHN.

iii) Applications: Used for utensils, shafts, nuts and bolts, pump parts, condenser tubes and similar applications where corrosion is not too severe.

b. Naval Brass

i) Composition: 60% Cu, 39% Zn, 1% Sn.

ii) Properties: Good corrosion resistance to marine environments.

iii) Applications: Used for marine hardware, propeller shafts, piston rods, nuts and bolt and welding rods.

c. Leaded Brass

i) Composition: 1-3 % Pb + Muntz metal or 1-3% Pb + Naval brass i.e., 61.5% Cu, 35.5% Zn, 3% Pb

ii) Properties:

1. Good machinability due to the presence of Pb
2. During casting care should be taken to avoid segregation due to difference in the Density. Addition of lead slightly decreases ductility and impact strength.

iii) Applications: Used for hardware, gears, and automatic high-speed screw machine parts.

d. Forging Brass

i) Composition: 60% Cu, 38% Zn, 2% Pb

ii) Properties: Best hot working properties

iii) Applications: Used for hot forging, hardware and plumbing parts.

e. High Tensile Brasses

Alloying elements such as Al, Fe, Mn, Sn, Ni are frequently added to 60-40 brass to increase its tensile strength

a. Manganese Bronze

i) Composition: 1% Mn, 2% Fe, 39% Zn and balance Cu.

ii) Properties: High zinc brass has high strength combined with excellent wear resistance. It also has a good resistance to seawater corrosion.

iii) Applications: Used for clutch dishes, extruded shapes, forgings, pump rods, shaft, Valve stems and welding rod, marine engine pumps, and propeller gears of ships.

f. Brazing Brass

i) Composition: 50% Cu, 50% Zn

ii) Properties: This brass is brittle due to the presence of gamma (γ) phase and can be crushed to powder manually or mechanically for its use in powder form.

iii) Applications: Used in joining of commercial brasses.

III. Bronzes

Bronzes are the alloys of copper containing elements other than zinc. In these alloys zinc may be present in small amount. Originally bronze was used to denote copper-tin alloys.

Classification:

Commercially important bronzes are described below:

A. Aluminum Bronzes

1. Manufacturing:

- Aluminum bronzes are the alloys of copper and aluminum in which copper is the base metal and aluminum is the alloying element.
- The equilibrium diagram is as shown in Fig. 2. The maximum solubility of Al in Cu is 9.4 % (at 565°C) and eutectoid transformation occurs at 11.8% Al. The beta (β)

Phase (analogous to γ in steels) transforms to $\alpha + \beta_2$ phase (analogous to pearlite in steels) on slow cooling. On quenching, the beta (β) phase transforms martensitically to β' phase without a change in the composition. β' phase can be tempered and shows the changes in the properties in a manner very much similar to the tempering of steels as shown in Fig. 2.

- Composition:** Commercial aluminum bronze contains Cu + Al (4-11%). Other elements such as Fe, Ni, Mn, and Si may be added to these bronzes for improvement of certain properties.
- Properties:**
 1. Good strength, ductility and toughness.
 2. Good bearing properties
 3. Good corrosion resistance
 4. Good fatigue resistance

iii) Applications:

1. Bronzes available in sheet, plate and tube forms (containing low % of Al 4-7%) are used in jewellery, cigarette cases, heat exchangers, chemical plants, etc.
2. Hot worked alloys are used for pump castings, valve fittings, propellers, cylinder heads, gears, dies, bearings, spark plug bodies and electrical contacts.

B. Tin Bronzes

1. Manufacturing:

- Tin bronzes are the alloys of copper and tin. The copper rich portion of copper-tin equilibrium diagram, which covers industrial alloys, is shown in Fig. 3.
- The solubility of tin in copper is 13.5% at 796°C, increases to 15.8% at 586°C and remains constant up to 520°C, decreases to 11% at 350°C and to about 1% at room temperature.
- A peritectic reaction occurs at 798°C in alloys containing 13.5 - 25% tin resulting in the formation of beta (P) intermediate phase.
- At 586°C, the beta (P) phase undergoes a eutectoid reaction and forms a mixture of $\alpha + \beta$. At 520°C, the γ phase undergoes another eutectoid reaction and forms a mixture of $\alpha + \delta$. The delta (δ) phase decomposes and gives a mixture of $\alpha + \epsilon$ phases by a third eutectoid reaction at 350°C. However this reaction is so sluggish that the ϵ phase is never seen in the microstructure of alloys cooled under industrial conditions i.e. for sand cast and air cooled alloys.
- The solubility limits are also affected by the cooling rate and alloys up to 8% tin usually show single-phase solid solution at room temperature even though the equilibrium solubility limit at room temperature is about 1%.
- Due to wide separation of liquidus and solidus curves, coring is usually observed in all cast alloys. Cast alloys containing more than 8% tin shows cored dendrites of α and $\alpha + \delta$ eutectoid.
- Annealing removes coring and also dissolves $\alpha + \delta$ eutectoid. This dissolution results in the formation of small pores due to the differences in volume of α and δ and results in leakage of pressure tight castings on annealing.

Classification:

Tin bronzes are divided into four groups on the basis of their content as below:

1. Alloys up to 8% tin
2. Alloys between 8-12% tin
3. Alloys between 12-20% tin
4. Alloys between 20-25% tin

1. Alloys up to 8% tin:

i) Composition: 92% Cu, 8% Sn.

ii) Properties: They are single-phase alpha-solid solution and have good ductility and malleability along with good corrosion resistance.

iii) Applications: They can be easily cold worked and hence are used in the form of sheets, wires and for coins.

2. Alloys between 8 - 12% tin

i) Composition: 88-92% Cu, 8-12% Sn.

ii) Applications: They are principally used for pumps, gears, heavy load bearings, and marine fittings to resist seawater corrosion.

3. Alloys between 12 - 20% tin

i) **Composition:** 80-88% Cu, 12-20% Sn.

ii) **Applications:** They are mainly used for bearings.

4. Alloys between 20 - 25% tin

i) **Composition:** 75-80% Cu, 20-25% Sn.

Some of the other important tin-bronzes are:

a. Coinage Bronze

i) **Composition:** 5% Sn, 1% Zn, balance Cu.

ii) **Properties:** Zinc increases the property of deoxidation of melt.

iii) **Applications:** It is widely used for the manufacturing of coins and hence the name.

b. Gun Metal

i) **Composition:** 10% Sn, 2% Zn, balance Cu.

ii) **Properties:** Zinc acts as a deoxidiser and also improves the fluidity of the melt.

iii) **Applications:** It is widely used for gun barrels and ordnance parts, marine castings, gears, bearings, valve bodies and similar applications.

c. Phosphor Bronze

These are alloys of copper and tin containing phosphorous.

Higher amounts of phosphorous than necessary for complete oxidation serves as an alloying element and improves the mechanical properties and cast ability by increasing the fluidity of melt.

Phosphor bronze is of two types as given below:

1. Wrought Phosphor Bronze

i) **Composition:** 2.5 - 8% Sn, 0.1 - 0.35% P, rest Cu.

ii) **Properties:** They are single-phase alpha (α) solid solutions and are good for cold working purpose.

iii) **Applications:** They are widely used for springs, wire gauges, wire brushes and Electrical contacts.

2. Cast Phosphor Bronze

i) **Composition:** 5-13% Sn, 0.3-1% P, rest Cu.

ii) **Properties:** Increase in P, increases the fluidity of the melt and general soundness of the casting. Addition of large amount of P (i.e. exceeding 1%) makes the casting excessively brittle and unsuitable for purpose.

iii) **Applications:** It is used for gears, bushings, slide walls and similar purposes.

3. Statuary Bronze

i) **Composition:** 10% Sn, 2% Zn, 2% Pb, rest Cu.

ii) **Properties:** Apart from increasing fluidity of melt, gives a brownish-black colour called patina of statues.

4. 80-10-10 Bronze

i) **Composition:** 9-11% Sn, 8-11 % Pb, rest Cu.

ii) **Applications:** Used for high-speed heavy pressure bearings and bushings.

5. 85-5-5-5 Bronze

i) **Composition:** 85% Cu, 5% Sn, 5% Zn, 5% Pb

ii) **Properties:** It has good castability and machinability and also reasonably good mechanical properties at low cost.

iii) **Applications:** It is widely used for bearings, low-pressure valves, taps, pipefittings, Small gears and ornamental fixtures.

III. Bearing Metals

Classification:

1. White metal alloys (Babbitt)
2. Copper lead alloys
3. Silver bearings
4. Tin bronzes
5. Aluminum alloys
6. Gray cast iron
7. Porous self- lubricating bearings
8. Dry and anti-corrosive bearings

a. White Metal Alloys:

i) Composition (%):

	Sn	Pb	Sb	Cu	Others
Pb-based	1-10	Balance	10-15	1.5-3.5	Cd: 1.25-1.75 As: 0-1.0
Sn-based	Balance	Up to 10	5-12	3-5	As:0-0.1

A typical alloy from lead-based Babbitt group contains 80% Pb, 10% Antimony and 10% Sn and from Tin-based Babbitt group contains 90% Sn, 5% antimony and 5% Cu.

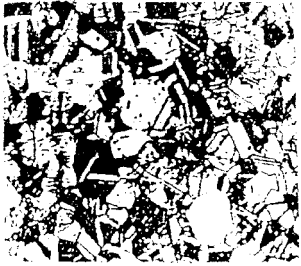
ii) Properties:

1. The microstructure of a Babbitt consists of hard cuboids of Sn-Sb in a soft matrix of eutectic. In addition to this the microstructure may consists of hard needles of Cu - Sn (or Cu₂Sn) and hard star shaped crystals of Cu₃Sn.
2. Tin based Babbitt has better corrosion and wears resistance as compared to lead based Babbitt.

iii) Applications:

Used for long diesel engine crankshaft (it consists of steel backing with an interlayer of copper lead and a thin top layer of lead tin alloy).

Microstructures



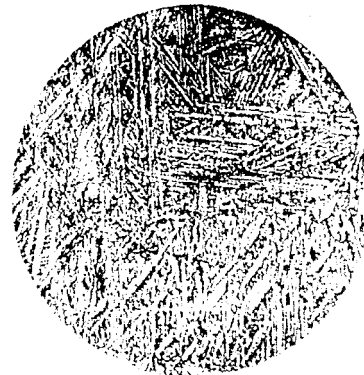
α - Brass



$\alpha + \beta$ Brass



90/10 aluminum bronze,
cast and annealed



90/10 Aluminum
bronze, water quenched



90/10 water quenched
Al-bronze from 900^o C

Figure 8.1 Microstructures of copper alloys

Experiment No. 9

Title: Observations in the change in mechanical properties due to change in microstructure.

Aim: To study the effect of annealing, normalizing and Hardening on microstructures and hence mechanical properties.

Equipment: Muffle furnace (capacity of up to 1200 c), Rockwell Hardness Tester.

Theory:

Heat treatment can be defined as heating and cooling the steels in a particular way to obtain desirable properties. Annealing, Normalizing and Hardening are the three major types of the heat treatments carried out in the industries.

Annealing can be defined as heating the steels to the austenitization temperature depending upon its composition and cooling it inside the furnace.

The basic purpose of annealing is to reduce the hardness (softening) or improve the ductility as per requirement. Usually this process is carried out as an immediate process. Simply change in the hardness of the steel before and after the process confirms the utility of the process.

Normalizing can be defined as heating the steels to the austenitization temperature depending upon its composition and cooling it in air. The basic purpose of Normalizing is to refine the grain size. This imparts fine grain size in the material there by increasing its hardness and toughness. Moderate increase in the hardness confirms the utility of the process. Usually this process is carried out as a final (finishing) treatment in the manufacturing cycle of a steel product.

Hardening can be defined as heating the steels to the austenitization temperature and quenching it in water or a suitable quenching media. The basic purpose of this process is to achieve maximum hardness in the steels. The maximum hardness is achieved by obtaining Martensite in the structure. This gives rise to a metastable structure. Hence this process is always followed by Tempering.

Procedure:

For annealing keep the specimen in the muffle furnace and perform heating to a suitable temperature. Shut off the furnace after suitable time and wait till room temperature is achieved.

For Normalizing, heat the specimen to the suitable temperature as in annealing. after suitable time, remove the specimen from the furnace and cool in air (Preferably under a fan).

For Hardening, heat the material as above and after attaining suitable temperature. remove the specimen and drop in a bucket of water at room temperature.

Observations:

Compare the Hardness of the steel specimen before and after the above treatments and comment.

Procedure:

1. Clean the objective and the eyepiece of the optical metallurgical microscope.
2. Take the prepared specimens.
3. Place them one by one under the optical metallurgical microscope.
4. Observe the microstructure of each of the specimens carefully.

Questions:

1. "Small additions of aluminum are frequently done to brasses for improvement of properties". Justify.
2. "3% to 5% Cu is generally added to tin based white metal alloys". Justify.
3. "Tin bronzes show pronounced coring". Justify.
4. What are brasses? How are they classified? Explain any two of them.

References:

1. Dr. Kodgire V D; Material Science and Metallurgy for Engineers; Everest Publishing House.
2. Avner S H; Introduction to Physical Metallurgy; McGraw-Hill Publication

Experiment No. 10

Title: study of the change in structures due to surface / case hardening of steels.

Aim: To study the effect of surface / case hardening on microstructures.

Materials: Induction hardened sample, Nitrided EN40B Steel specimen.

10.1 Theory:

10.1.1 Surface Hardening:

This method is based on the fact that the properties of steel not only depend upon the chemical composition but also upon the presence of various phases and microconstituents. A Steel having a definite chemical composition is soft when ferrite and pearlite are present, but it becomes hard when Martensite is present. Such a distribution of various phases at the surface and at the center is obtained by a special heat treatment, called surface hardening. In surface hardening the aim is to obtain hard Martensite phase at the surface and soft ferrite and pearlite microconstituents at the center of the steel. This could be achieved in

- a) The steel should be heated in such a way that the austenite forms at the surface only and negligible pearlite to austenite transformation takes place at the center.
 - b) After obtaining such a distribution of various across the specimen, it is cooled rapidly so that martensite forms at the surface.
- The above-mentioned distribution of microconstituents along the cross section of steel can be obtained by special heating method, which will produce a temperature gradient.

10.1.2 Flame Hardening:

Flame Hardening is a heat treating process in which the surface of steel is heated rapidly above the transformation temperatures by a high temperature flame and then quenched to produce martensite.

In flame Hardening the high temperature flame is obtained by combustion of a fuel gas with oxygen or user, for example, oxy - acetylene flame, which can generate temperatures up to 3000°C . Fixed gas burners can also be used for the above purpose.

These flame heating equipments can heat the part in different ways, such as the spot method, the progressive and the spinning method. In these different methods either the flame is stationary and the object moves, or the flame moves progressively or the object spins. After obtaining the required temperature at the surface of the object, the flame is removed and the object is quenched either by spraying or by immersion in water.

The success of many flame hardening applications depends largely upon the skill of operator. The principal operating variables are as follows:

- i) Distance between the gas flames and the work surface
- ii) Gas pressures and ratios
- iii) Rate of travel of flame - head or work
- iv) Type, volume and application of quench

These variables must be closely controlled to obtain the desired surface and depth of hardness. It is very difficult to judge the correct hardening temperatures. It generally results either in understanding or overheating.

10.1.3 Induction Hardening:

An electrical conductor (such as steel) can be heated by electromagnetic induction by passing an alternative current through an inductor, or work coil. When alternating current is passed through the work coil, a rapidly alternating magnetic field is established within the coil. The magnetic field is thus established induces an electric potential in the part to be heated and because the part represents a closed circuit, the induced voltage causes the flow of current, I through the conductor. The resistance R offered by the coil to the flow of induced current causes heating. The heat produced in the conductor is proportional to I^2R . The pattern of heating is determined by the shape and design of the induction coil, and the rate of heating, by the strength of the magnetic field.

The distribution of induced current in the part to be heated is maximum on the surface and decreases rapidly towards the center of the part. This phenomenon is also known as Skin effect. This effect increases with increase in frequency of induction heating. Induction results in immediate heating and production of high temperatures at the surface. Heat is later transferred towards the center only by conduction. Therefore this method of heating produces a steep temperature gradient from the surface towards the center.

10.1.4 Case – hardening of steel:

Hardness of steel is mainly determined by the percentage of carbon. As the percentage of carbon increases beyond 0.2 percent Hardness increases rapidly after quenching. The same result can be achieved by increasing the nitrogen content at the surface, which results in the formation of nitrides.

The above principle of hardening is used in case - hardening. Low - carbon steels are heat treated to increase carbon and nitrogen contents at the surface of the part. Carbon and nitrogen contents at the surface of ferrous alloys can be increased by many methods, such as, carburizing, nitriding, carbonitriding and cyaniding.

10.1.5 Carburizing:

Carburizing may be defined as a method of heat treatment by which carbon content at the surface of a ferrous material is increased. Depending upon the type of carbon rich atmosphere used, the carburizing process can be classified in three groups, Pack Carburizing, gas carburizing and liquid carburizing.

10.1.6 Nitriding:

Nitriding is a case hardening process by which nitrogen content at the surface of the steel is increased. It is based on the fact that active nitrogen can be absorbed by the ferrite phase of iron and certain other metallic elements. Ferrite phase can dissolve up to 0.6 percent at nitrogen at 550 to 650°C . Nitrogen also forms nitrides with iron, aluminium, chromium, molybdenum, etc. Depending upon the type of medium used, nitriding process could be of two types, gas nitriding and liquid nitriding.

10.1.7 Carbonitriding

Carbonitriding is a process by which carbon and nitrogen content are added to the surface of the steel. It is also known as gas cyaniding or nitrocarburizing. Carbonitriding is modified gas carburizing process in which ammonia is added in to the gas-carburizing atmosphere in order to add nitrogen to the carburizing case.

10.1.8 Cyaniding:

Cyaniding is a process by which carbon and nitrogen content at the surface of steel are increased. It is called as liquid carbonitriding.

10.2 Procedure:

1. Clean the objective and the eyepiece of the optical metallurgical microscope.
2. Take the prepared specimens.
3. Place them one by one under the optical metallurgical microscope.
4. Observe the microstructure of each of the specimens carefully.

Questions:

Q.1 What is the relative advantages and disadvantages of hardening at the surface, and hardening through out the section of a work piece?

Q.2 Are non - ferrous alloys case hardened? If yes give suitable examples.

Reference:

1. B. K. Agrawal, "Introduction to Engineering Materials"; T M H, New Delhi 1988.

Experiment no. 11

Magnetic particle crack detector

Title: Magnetic particle crack detector
Objective: to detect invisible surface or subsurface defects.
Equipment: Magnetic particle crack detection machine.

Equipment details:

Principle:

The function of the equipment is to provide high amperage, low voltage magnetizing current used for creating a temporary magnetic field in the object of inspection for detection of faults by application of magnetic particle inspection technique.

When the material or part under test is magnetized, magnetic discontinuities that lie in a direction generally transverse to the direction of the magnetic field will cause a leakage field to be formed at and above the surface of the part.

The presence of this leakage field and therefore the presence of the crack/discontinuity are detected by applying fine dust of Ferro magnetic particles over the surface. This magnetically held collection of the particles forms an outline of the crack/discontinuity and locates exact shape, size and extent.

Theory:

There are three methods of magnetic particle inspection:

I] dry method:

When a piece of metal is in magnetic field and the lines of magnetic flux get intersected by a discontinuity such as crack, magnetic poles are introduced on either side of the discontinuity. The discontinuity causes abrupt change in the path of magnetic flux flowing through the material normal to the discontinuity, resulting in a local flux leakage field and interference with the magnetic lines of force. This flux disturbance can be detected by its effect on the magnetic particles which collect on the region of discontinuity.

II] wet method

In wet method the powder is suspended in low viscosity non-corrosive fluid. Special fluorescent ferromagnetic powder is applied by wet method in the magnalo method. The component is inspected in a dark room with ultra violet light.

Operating procedures:

1. Check input power supply before you plug the mains supply cable. Requirement is 230V AC, 1 phase, 50Hz, with good earth connection and 25 Amps. Power socket.
2. Lay two high current cables straight and parallel.
3. Plug on the other end of current cables to terminal marked COM & AC
4. Machine is set ready now for the work.
5. Select either magnetization or demagnetization process by the rocker type switch.

Circular magnetization:

Circular magnetization is achieved by passing direct current with the help of prods through the test object. Circular magnetic field is produced right angle to the flow of current. By circular magnetization cracks in longitudinal directions are seen.

Longitudinal magnetization:

Wind 3-4 turns of high current cable around the test part and pass AC current through cable. Longitudinal magnetic field is produced in the test part, which is used for detecting cracks in transverse directions.

Guidelines for surface crack check:

1. position the cables marked on COM and AC
2. Touch the tip of the prods on the test object firmly and pass current momentarily to check localized sparking.
3. Sparking or burning mark can be avoided by cleaning surface of tip/ test object and by firm contact.
4. Check adequacy of magnetic field strength and magnetic powder bath concentration with the help of ASTM test piece.
5. Horizontal line and two 45° lines on either side should be visible.
6. In case lines on ASTM piece are not clear, gradually increase current control and recheck the clarity.
7. For maximum output current duration time is 2 -3 secs.

Guidelines for subsurface defect check:

1. Position the cables on COM and HWDC.
2. Touch the tip of the prods on the object firmly and pass current momentarily to check localized sparking.
3. Sparking or burning mark can be avoided by cleaning surface of tip/ test object and by firm contact.
4. For checking subsurface defects use of dry magnetic powder is recommended.
5. For subsurface crack detection, prod spacing of maximum 6" is recommended.

Questions:

1. Why magnaflux testing is called non-destructive testing?
2. Why demagnetizing is necessary?

